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A

FAMILIAR INTRODUCTION

TO THE STUDY OF

POLARIZED LIGHT;

WITH

A DESCRIPTION OF, AND INSTRUCTIONS FOR USING,

THE

TABLE AND HYDRO-OXYGEN

POLARISCOPE AND MICROSCOPE.

BY

CHARLES WOODWARD, F.R.S.

PRESIDENT OF THE ISLINGTON LITERARY AND SCIENTIFIC SOCIETY.

ILLUSTRATED BY NUMEROUS WOOD ENGRAVINGS.

SECOND EDITION.

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PREFACE

TO THE FIRST EDITION.

Messrs. Smith & Beck having requested me "to oblige them with a description of, and instructions for using, my Table and Hydro-oxygen Polariscope and Microscope," and several friends possessing achromatic microscopes fitted with the polarizing apparatus having lamented the difficulty of comprehending the laws of the phenomena thereby exhibited, I have endeavoured to render the use of these instruments more interesting, by presenting, in a concise and familiar manner, such introductory information as may smooth the threshold of a subject confessedly abstruse, and lead to the study of works of far higher pretensions and deeper research.

I have briefly noticed those facts which have gradually led to the very general adoption of a theory concerning the nature of light differing in some important respects from that advanced by Sir Isaac Newton; and I have endeavoured to shew that his successors, whilst they have adopted another theory, have yet done little more than given new names to old facts, leaving his discoveries and his calculations still to form the firm basis of the science.

During my earlier studies I read many works connected with the subject of light, and have, no doubt, almost imperceptibly adopted the ideas of others, when they were subsequently confirmed by my own observations or experiments. As, however, the following pages have been written without referring to any but a few notes forming the outlines of lectures on the polarization of light, which, as an amateur, I have occasionally delivered in a popular style, I am now only able to acknowledge my obligations *generally* to those who may have assisted my investigations, and to evince my gratitude by attempting to facilitate the inquiries of others.

C. W.

COMPTON TERRACE, ISLINGTON,
APRIL 1848.

PREFACE

TO THE SECOND EDITION.

HAVING undertaken to prepare for Messrs. SMITH & BECK another edition of my "Familiar Introduction to the Study of Polarized Light," I readily embrace the opportunity thus afforded me of tendering my thanks to the many scientific friends who have expressed their approbation of the attempt "to facilitate the inquiries" of those who desire to study this highly interesting but "confessedly abstruse" branch of science.

Some few, indeed, have intimated that I should have prosecuted the subject still further; but this could scarcely have been accomplished without defeating the professed object of "presenting, in a concise and familiar manner, such introductory information" as might prepare the inquirer for "deeper research."

I have, however, carefully revised the whole; and by altering Figures 9 and 10, and adding two others illustrative of the polarization of light by reflection, I trust it will be found that I have more clearly explained that part of the subject.

C. W.

COMPTON TERRACE, ISLINGTON,
JUNE 1851.

PART I.

A

FAMILIAR INTRODUCTION

TO THE STUDY OF

POLARIZED LIGHT.

(1.) Philosophers, at a very early period, attempted to investigate the nature of light, and, until the time of Newton, they generally concurred in opinion that it is produced by some affection of the particles of matter, and is not itself a material agent.

(2.) Aristotle observed that light is not fire, nor is it any thing bodily radiating from the luminous body, and transmitted through a transparent one; but the mere presence of fire, or some other luminous body, at a transparent surface.

(3.) The followers of Descartes considered that light as it exists in the luminous body is nothing but a power or faculty of exciting in us a very clear and vivid sensation; that in the hidden pores of transparent bodies there is a certain subtile matter, which, by means of its exceeding smallness, can penetrate even glass; and that this matter is impelled by the luminous body so as to affect the organ of sight.

(4.) Malebranche explained the nature of light from a supposed analogy between it and sound. He considered that all the parts of a luminous body are in a rapid motion, which, by very quick pulses, is constantly compressing the subtile matter between the luminous body and the eye, and exciting vibrations: as these vibrations are greater, the body appears more luminous; and as they are quicker or slower, the body is of a different color.

(5.) Huyghens supposed that an exceedingly thin and highly elastic medium, called ether, fills all space, and occupies the intervals between the particles of all substances; that luminous bodies excite vibrations in this ether, which spread like waves formed by dropping a stone into still water; and that the ethereal vibrations, impinging on the retina of the eye, produce the sensation of light in the same way as the undulations called sonorous, affecting the auditory nerve, produce the sensation of sound.

(6.) Newton objected, that if light, like sound, be propagated by undulations, like sound, it would pass through bent tubes, which he considered contrary to fact; hence he supposed light to consist of material particles emitted by luminous bodies, and moving through space with an immense velocity.

(7.) To this it was objected, that as light is ascertained, by repeated observations on the eclipses of Jupiter's satellites and the aberrations of the fixed stars, to be propagated at the rate of 192,000 miles in a second, its particles, if material, ought to acquire a momentum; but that no indication of such an effect had ever been experienced even by that delicate organ the eye. Newton's objections, however, prevailed; his views were generally adopted under the name of the corpuscular theory, and the question as to the propagation of light was supposed to be decided.

(8.) But the attention of philosophers had been for some time directed to the dark bands seen when light passes through very narrow apertures. If, for instance, we hold the hand between the eye and a bright cloud, or the ground glass of a lighted lamp, and open the fingers so as to admit the smallest portion of light, we shall perceive dark bands intersecting the luminous space at regular intervals.

(9.) Little progress was, however, made towards the explanation of this phenomenon until Dr. Young pointed out a principle upon which it could be accounted for, and which he termed the *interference* of the waves of ether.

(10.) Dr. Young admitted a sunbeam through a hole made with a fine needle in thick paper, and brought into the diverging beams a slip of card one-thirtieth of an inch in breadth, and observed its shadow on a white screen at different distances. The shadow was divided by light and dark parallel bands alternately arranged, but the central line was always white. He then intercepted the light on one side by a second card interposed between the first card and its shadow, and allowed the rays to pass freely on the other side, when all the bands immediately disappeared; and he thus proved, beyond all doubt, that they were occasioned by the interference of the light passing on both sides of the first card.

(11.) From this experiment it is evident that, as the central line in the shadow was always white, light can turn a corner, though, from the extreme minuteness of the undulations, not to the same extent as sound does; and thus one of the greatest objections to the undulatory theory is removed (6): and it is also evident that two rays of light may be so superposed as to produce darkness, a result which cannot be explained on the corpuscular theory, although it can be easily accounted for on its rival, which is called the undulatory, being perfectly analogous to the effects produced by the interference of the waves of both water and air.

(12.) For if we stand at the confluence of two rivers, when the streams or tides are running down against a strong wind, equally opposed to each, we shall perceive that, when the waves from the two rivers meet in the same state of vibration, they will form large waves; but when they differ half a wave, the high part of one will fill up the hollow of the other, and the water will be comparatively smooth.

(13.) Again; if we put the arms of a tuning fork into a state of vibration, and hold it over a glass vessel of such a capacity as that the air in the glass will vibrate in unison with the arms of the tuning fork, a continuous sound will be heard so long as the arms continue to vibrate. But if we take a similar glass vessel, and hold it at right angles to the first, somewhat as if pouring the contents of one into the other, the sound will cease, as completely as the sound of a piano-forte ceases when the vibrations of the strings are stopped by the damper, because the undulations in the one will interfere with and neutralize those in the other. If we remove the upper glass vessel, the sound is again heard, and so on alternately; and thus the alternations of sound and silence are analogous to the alternate bands of light and darkness.

(14.) The nature and effects of interference may, however, be more readily explained by a diagram.

Fig. 1.

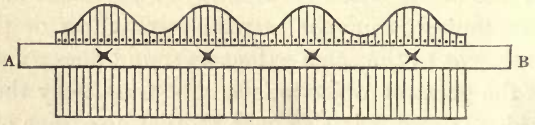


Fig. 2.

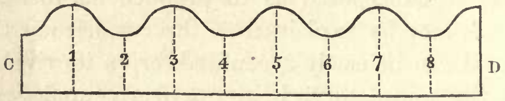


Fig. 1.—A model of waves with moveable rods.
Fig. 2.—A solid model with fixed waves.

A B, *Fig.* 1, represents a model with square bars or rods freely moving in a perpendicular direction through the frame A B, and furnished with pins resting upon the upper part of the frame, so that, when at rest, the whole may assume the appearance of waves, as in the diagram.

C D, *Fig.* 2, represents a solid model with fixed waves of similar size or intensity, and numbered so as to distinguish each half undulation.

(15.) Now it will be seen, that, when the stars indicating the highest part of the waves on A B correspond with the odd numbers of half undulations on C D, each system of waves will be in the same state of vibration; and if so superposed, a series of waves of doubled intensity will be the result, as in *Fig.* 3.

Fig. 3.

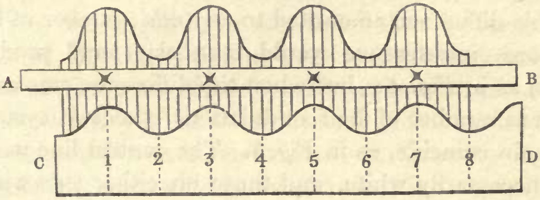


Fig. 4.

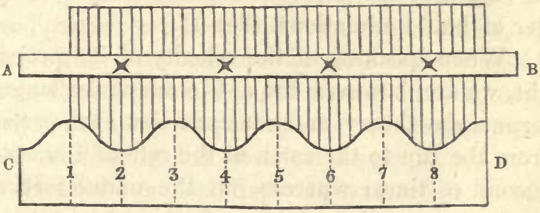


Fig. 3.—Intensity of waves doubled by the superposition and *coincidence* of two equal systems.

Fig. 4.—Waves neutralized by the superposition and *interference* of two equal systems.

(16.) If, on the other hand, the two systems be so superposed as that the stars on A B shall coincide with the even numbers on C D, as in *Fig.* 4, there will be a difference of half an undulation in the two systems: the one will neutralize the other by interference, and darkness will be the result.

(17.) If C D be constructed so that A B may be moved forward indefinitely, it will be obvious that the waves will be equally increased in intensity by a difference in the two systems of any *even* number, and neutralized by a difference of any *odd* number of half undulations.

(18.) Thus, in Dr. Young's experiment, the systems of waves passing on each side of the card would meet in the centre of the screen in the same state of vibration, this line being equidistant from the two edges of the card, and hence would be illuminated by the sum of the lights passing by them. But on either side of this line there would be a difference in the length of the paths of the two systems, increasing with the distance from the central line. When this difference amounted to any *odd* number of half undulations, interference would take place and produce darkness, as in *Fig.* 4; but when the difference amounted to any *even* number of half undulations, the two systems would again coincide, as in *Fig.* 3. The central line would then be necessarily white, and those on either side would be alternately dark and light, as the increasing difference in the length of the paths amounted to an odd or even number of half undulations. (See 17.)

(19.) When speaking of the velocity of the propagation of light, we are, however, too apt to adopt the language of the corpuscular theory, and conclude that each particle travels from the sun to the earth at the rate of 192,000 miles in a second of time; whereas, on the undulatory theory, we merely suppose the particles of ether to be successively excited into waves of vibrations by the illuminating body, as the waving corn by the wind, when, although the ears themselves remain attached to the same part of the earth by their roots, yet they produce by their vibrations those beautiful undulations which appear to flow from one end of the field to the other, the progression of the waves being at right angles to the plane of vibration.

(20.) A familiar illustration may afford us more correct views respecting the velocity with which motion may be propagated and matter affected without the transmission of matter itself. If we fill a boy's pea-shooter with peas, and hold it in a horizontal position, it will be obvious that, as soon as we force in an additional pea at one end of the tube, a pea will drop out at the other; and if we suppose a similar tube extending from London to York, and that we could move the whole line of peas in such a long tube with as much facility as that in the short one, it would be evident that, almost as soon as an additional pea was put into the tube at London, a pea would drop out at York. Now, had the means whereby such motion was communicated been as imperceptible as those by which light is propagated or electricity transmitted through good conductors, we might have concluded that the same pea had travelled from London to York in an inconceivably short space of time; we should have been astonished at the apparent velocity of its transmission, and surprised that it had not acquired a momentum: but, knowing the conditions of the proposition, we perceive that the particles of matter may be affected, and motion propagated almost instantaneously throughout a very long line, although each individual particle may not be far removed from its original position. This illustration may also convey some idea respecting the instantaneous affection of matter, and, consequently, instantaneous propagation of motion from one station to another by the electrical telegraph.

(21.) Newton was the first who attempted to analyze light, and found that of the sun to be composed of seven differently colored rays, viz. red, orange, yellow, green, blue, indigo, and violet, each varying in refrangibility, from red, the least, to violet, the most refrangible: of these, the red, yellow, and blue, are considered primary colors, the others being merely compounds of two of these three.

(22.) Before Newton investigated the theory of light, Dr. Hooke had succeeded in splitting mica into films of such extreme thinness as to shew brilliant colors: one gave a yellow, another a blue, and the two together a deep purple; but as the thickness of the plates was less than the twelve-thousandth part of an inch, it seemed impossible by actual admeasurement to determine the law according to which the color varied with the thickness of the film. Newton, however, surmounted this difficulty by laying a double convex lens, the radius of whose convexity was fifty feet, upon the flat surface of another lens, so that the two surfaces were in contact at the centre, the distance between them increasing with the increased distance from that centre. A plate of air was thus inclosed between the two lenses varying in thickness in a certain known ratio as the surfaces of the lenses receded from each other.

(23.) When white or undecomposed light was allowed to fall upon these lenses, a very minute black spot was observed at the centre, while every different thickness of the plate of air gave different colors; and as the same thicknesses occurred all round at the same distances from the centre, the point where the two lenses touched was the centre of a number of concentric and differently colored rings.

(24.) He then by a prism decomposed a beam of white light, and allowed the different colors of the spectrum to fall successively upon the lenses. In each case the rings appeared, but no longer exhibited any variety of tint, the central spot being surrounded by rings of the same color as the light incident upon the lenses, separated by dark rings; but yet with this difference, that the rings formed by the less refrangible rays were broader than those formed by the more refrangible, so that the rings were broadest in red light and narrowest in violet.

(25.) In prosecuting his inquiries, he ascertained that, at whatever thickness of the plate of air the colored ring first appeared, there would be found at twice that thickness the dark ring, at three times the colored, at four times the dark, and so on, the colored rings regularly occurring at the odd numbers, and the dark rings at the even ones. But, upon looking through the lenses towards the light, the order was found to be reversed; for the colored rings were then seen at the even and the dark rings at the odd numbers; the colored light appearing to be reflected and not transmitted at the odd numbers, and to be transmitted and not reflected at the even ones. Hence a ray of light appeared at certain intervals to be in alternate states of easy transmission and easy reflection; in order, therefore, to give names to facts which he had proved to exist, and not to introduce a theory, Newton called these changes "fits of easy transmission and easy reflection."

(26.) If we now refer to the diagrams, we shall see how beautifully these phenomena are explained by the wave theory. For this purpose the reader's attention is directed to the following figure, which shews the "rings," usually known as Newton's, when seen by the reflection and transmission of red light.

Fig. 5.

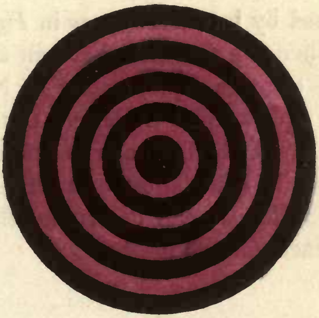
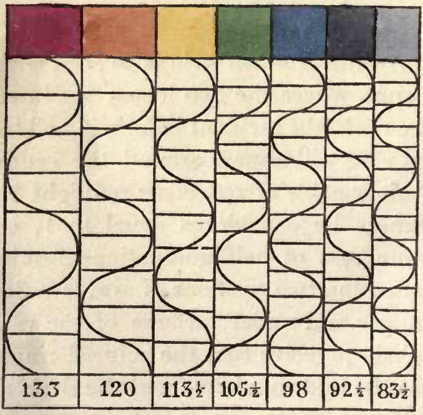


Fig. 5 represents Newton's rings as seen with red light. The central spot, where the two lenses are in contact, will necessarily be dark, the incident light being all transmitted; but a colored ring will appear around the centre, where a thickness of air capable of reflecting red light first obtains. If this thickness be considered equal to 1, and we add thereto the numbers of half undulations forming the difference between the two systems of waves reflected to the eye by the upper and under surfaces of the various thicknesses, we shall perceive that the colored rings will regularly occur at the odd numbers, and the dark rings at the even ones. (25.)

(27.) Let *Figs.* 1 and 2 represent two equal systems of waves for red light, the one reflected to the eye from the upper and the other from the under surface of Newton's thin plates of air. If they be superposed, as in *Fig.* 3, the waves will coincide, and there will be red light, as in the first colored ring. On moving A B a distance equal to one half undulation, as in *Fig.* 4, the waves will be neutralized by interference, and there will be darkness; on moving A B a second half undulation, there will be light; on moving it a third, there will be darkness, a fourth light, and so on; for when the stars indicating the highest part of the waves of A B coincide with the odd numbers of half undulations of C D, there will be light, as in *Fig.* 3; and when they coincide with the even numbers, darkness will be occasioned by interference, as in *Fig.* 4.

(28.) Thus, then, we perceive that half an undulation of a wave for each color is equal to one of Newton's "fits" for that color, and is equal in length to the thickness of the plate of air at which that color is first reflected. This he has ascertained by calculation, and hence we have before us the data by which we can determine the length of an undulation for each colored light.

Fig. 6.



Relative thicknesses of the plates of air by which each color is first reflected.

(29.) *Fig.* 6 represents the relative thicknesses of the plates of air at which each colored light was first reflected, and they are found to be as about 8 for red light to 14 for violet in a given space, or, more accurately, as 1 to 1·58; but the most astounding fact is, that the unit of the numbers 133, &c. is but the ten-millionth part of an inch, and which numbers Newton supposed to indicate the diameters of the molecules of each differently colored light. Taking, then, the half undulation as equal to one of Newton's spaces or fits, and the whole undulation as equal to two spaces, or what he termed the length of an interval between the fits of easy reflection, it will follow, that, if we draw waves so as to occupy each one interval or two spaces, we shall ascertain not only the relative proportions of the waves, but that the length of an undulation for each colored light is as follows:—

For	Red light,	266	ten-millionths	of an inch;
,,	Orange	240	,,	,,
,,	Yellow	227	,,	,,
,,	Green	211	,,	,,
,,	Blue	196	,,	,,
,,	Indigo	185	,,	,,
,,	Violet	167	,,	,,

And so, as the various notes in music are determined by differences in the frequency of the aërial pulses, in like manner differences of color are determined by differences in the frequency of the ethereal undulations; and as the deeper the arc of vibrations producing sound the stronger the tone, so the more ample the undulations the more intense the color.

(30.) The interference of the waves of simple or homogeneous light will, as we have observed (16), produce darkness; and we have now to explain why the interference of the waves of compound or white light will produce colors, as seen in mother-of-pearl, Barton's buttons, &c., and which are evidently caused by inequalities in their surfaces, as impressions taken on black wax will reflect the same colors.

(31.) In order, however, to simplify this subject, we will notice only the three primary colors, red, yellow, and blue, which by their combination will form white light.

(32.) When white light is reflected from the upper and under surfaces of very minute grooves, as those which really exist in mother-of-pearl and Barton's buttons, although impalpable to the touch and invisible to the unassisted eye, there will be a difference in the length of the paths of the waves reflected from the two surfaces equal to the depth of the minute groove; while the distance of the paths from each other being only equal to the width of such groove, the two systems of waves will not be sufficiently separated to prevent interference. If the difference in the length of the paths amount to any even number of half undulations, the two systems of waves will coincide, and produce a color equal to the intensities of the two combined; but if this difference should amount to any odd number of half undulations, the two systems would neutralize each other, and produce darkness (17). Thus, suppose the two systems of waves for red light to meet in the same state of vibration, the intensity of the red light would be doubled; and if at the same time the respective systems for yellow and blue were to meet in similar states, the intensities of the yellow and blue being also doubled, white light would be the result; for the red, yellow, and blue, would be combined in the same relative proportions: but if the respective systems for red and yellow should coincide, and those for blue should interfere, the combination of red and yellow would produce an orange, which could only form white light by the addition of the blue neutralized by interference, and which is called its *complementary color*, or that color which is required to make up the full *complement* of colors necessary for the production of white light; and so, if the systems of waves for red light should interfere, and those for yellow and blue should coincide, the result would be green light, which would require its complementary color, red, to form white light.

(33.) A minute difference in the distances through which the ethereal waves are propagated is thus necessary for the production of colors by interference; and this difference may be obtained not only by reflection from the two surfaces of minute grooves, but also by transmission through any doubly refracting body.

(34.) It is well known that refraction depends not merely on the obliquity with which a ray falls on the refracting medium, but also on the density of the medium itself; hence, if the particles of a body be operated upon, either *naturally* or *artificially*, so as to produce unequal elasticities in different directions, the refraction of light through that body will be unequal in such directions; and if the surfaces be parallel, the paths pursued by the differently refracted rays will necessarily be unequal also in their lengths; and thus, while double refraction is the result, there will be such a minute difference in the length of the paths pursued as may produce interference.

(35.) A rhomb of Iceland spar is an example of the *naturally* unequal elasticities or densities in a body, and, if we transmit a ray of light through it, the ray will suffer bifurcation: one part will be refracted according to the ordinary laws of refraction, and is called the *ordinary ray;* the other part will be refracted according to some extraordinary law, and is called the *extraordinary ray;* and two images of the object from which the ray emanated will be produced.

(36.) If we take a cube of regularly annealed glass, whose elasticity is the same in every direction, and submit it to the pressure of a screw, or to the action of heat, *unequal elasticities* will be produced by what may be termed *artificial means,* and double refraction will be the result. In this case there will be a sufficient difference in the length of the courses pursued by the ordinary and extraordinary rays to produce color by interference, though not a sufficient separation to cause two images.

(37.) Double refraction, then, may produce color by interference, and color will be the test of double refraction when the rays are not sufficiently separated to form two distinct images.

(38.) The interesting phenomenon of the polarization of light was accidentally discovered by Professor Malus in 1808, while viewing through a doubly refracting prism the light of the setting sun reflected from a French glass window, which happened to stand open, "like a door on its hinges," at an angle which must have closely approximated that of 56° 45′, and which has since been ascertained to be the polarizing angle for glass.

(39.) If we allow a beam of the sun's light to fall upon a plate of glass at any other angle of incidence than that of from 56 to 57 degrees, one portion of the light will be transmitted and another part reflected; and if we hold a second plate of glass over the reflected ray, a second reflection will take place, on whatever side of the reflected ray the second glass be held; but if the two glasses be so placed that the sun's light shall fall upon the first and the reflected light upon the second glass at an angle of incidence of 56° 45′ from the perpendicular, the light reflected by the first will be again reflected by the second glass when the planes of the two glasses are parallel to each other; but if, without altering its angle to the horizon, we turn the second glass a quarter of a circle, the light will be transmitted and not reflected: if we turn it another quarter, the light will be reflected and not transmitted; and so on alternately for every quarter of a revolution that the second glass is made to perform round the ray reflected by the first glass.

(40.) A ray of light, then, when reflected at an angle of incidence of 56° 45′ from the perpendicular, has undergone some modification: it has acquired the properties of sides;

it has two sides on which it can and two on which it cannot be again reflected; and as these opposite properties of the different sides were supposed to bear some analogy to the opposite properties of the different poles of a magnet, a ray of light so modified was said to be *polarized.* It is, however, universally admitted that the term is unfortunate, as it affords no indication of the phenomena it professes to describe.

(41.) In order to develop by degrees a subject confessedly abstruse, we have hitherto noticed only one plane of vibration of the ethereal particles; but Fresnel assumes that the vibrations are performed in two planes at right angles to the direction of the progress of the wave, which is analogous to the motions of the waves of the sea, as experienced by those who have crossed the channel in a steam-boat during a brisk gale, when the rectangular vibrations occasioned by the alternate *pitchings* and *rockings* of the vessel have caused the mast-head to describe a circle or an oval, as the case might be, and afforded those who could enjoy the scene a fine opportunity of studying the resolution of forces.

(42.) Before, however, we attempt to explain the nature of polarized light, it may be expected that we should define the term, and thus answer the oft repeated question, What is it? We may say, It is light reflected from or transmitted through glass at an angle of incidence of 56° 45′; but this only describes one of the modes of producing it, and is no reply to the question, What is it? As this can be most readily answered by hypothesis, we shall endeavour to shew, that, *in the language of the undulatory theory,* it is light propagated by only *one plane* of vibrations; whereas common light—and this term is merely used in contradistinction to that of polarized light—is propagated by several or at least two planes at right angles to each other; and that the act of polarizing light is, *in the same language,* the act of separating or modifying these rectangular planes, so that the vibrations may be reflected or transmitted in *one plane* only.

(43.) Let A B, *Fig.* 7, represent the perpendicular and C D the horizontal vibrations of the ethereal particles, by which a ray of common light is supposed to be propagated; and let E F and G H represent the two plates of glass used as reflectors.

Fig. 7.

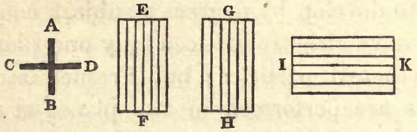


Fig. 8.

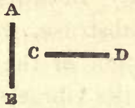


Fig. 7.—A B, C D, rectangular vibrations for common light.
E F, G H, I K, plates of glass used as reflectors.

Fig. 8.—A B, the perpendicular vibrations transmitted; C D, the horizontal vibrations reflected by E F.

(44.) Now we can readily conceive that the ethereal particles which vibrate perpendicularly to the plane surface of a plate of glass will be more likely to communicate motion to the ethereal particles within the glass, than those which vibrate horizontally upon it; and, if motion be communicated to the ethereal particles within the glass, the vibrations will be continued, and transmitted through the glass; we can also as easily conceive that the ethereal particles which vibrate horizontally upon the glass will be more likely to rebound, or, in optical language, to be *reflected*, than those which vibrate perpendicularly to it.

(45.) When, then, a ray of common light falls on a plate of glass, as E F, *Fig.* 7, at the polarizing angle, the perpendicular vibrations A B are transmitted and the horizontal vibrations C D are reflected. A B, *Fig.* 8, will then represent the vibrations of the transmitted and C D those of the reflected light. C D after reflection from E F would be again reflected by G H, but if G H were turned a quarter of a circle as I K, C D would be transmitted and not reflected.

The plate E F *polarizes* the light in two planes at right angles to one another, by transmitting the perpendicular vibrations A B, and reflecting the horizontal vibrations C D, as in *Fig*. 9.

If now G H be held over E F, and parallel to it, the horizontal vibrations C D reflected by E F will be again *reflected* by G H, because both plates will be in the same relative position with respect to C D.

Fig. 9.

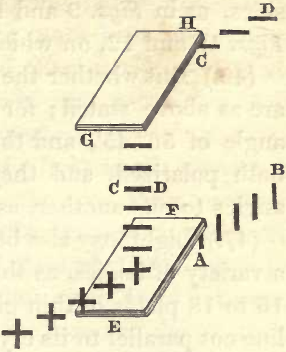


Fig. 9.—The perpendicular vibrations A B transmitted by E F.—The horizontal vibrations C D reflected first by E F, and again by G H.

Fig. 10.

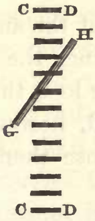


Fig. 11.

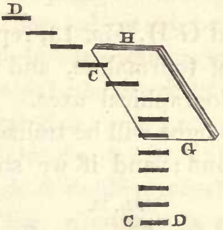


Fig. 12.

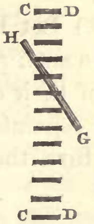


Fig. 10.—The horizontal vibrations C D, which had been *reflected* by E F, *transmitted* by G H turned one quarter of a circle.

Fig. 11.—C D *reflected* by G H turned a second quarter.

Fig. 12.—C D *transmitted* by G H turned a third quarter.

But if G H be turned one quarter of a circle round C D, as in *Fig*. 10, C D will then vibrate perpendicularly to the plane surface of G H, and will be *transmitted*.

If G H be turned round a second quarter of a circle, as in *Fig*. 11, C D will again vibrate horizontally upon it, and be *reflected*.

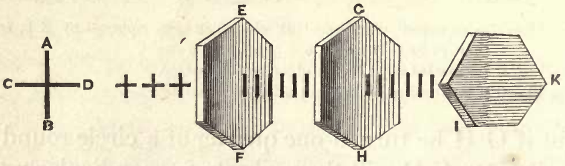
If G H be turned a third quarter, as in *Fig*. 12, C D will vibrate perpendicularly to it, and be *transmitted;* and so on alternately for every quarter of a circle that G H is turned round C D: and thus light is said to be polarized, or to have acquired the property of sides, there being two sides, as in *Figs.* 9 and 11, on which it is, and two, as in *Figs.* 10 and 12, on which it is not, again reflected (40).

(46.) But whether the theory be correct or not, the facts are as above stated; for the ray reflected from glass at an angle of 56° 45′, and the ray transmitted through it, are both polarized, and they are polarized in planes at right angles to one another, as A B and C D, *Figs.* 8 and 9.

(47.) Light may also be polarized by *transmission* through a variety of bodies, as through a bundle consisting of from 16 to 18 plates of thin glass, or through a plate of tourmaline cut parallel to its crystallographical axis. Of these the tourmaline is the most perfect, and, therefore, the most useful polarizer: it is a doubly refracting crystal, and occurs in long prisms, which may be cut into parallel plates sufficiently transparent to allow light to pass through them.

(48.) Let E F and G H, *Fig.* 13, represent the surfaces of two such plates of tourmaline, and the lines the direction of their crystallographical axes. If we look through them separately the light will be transmitted, however we may turn them round; and if we superpose them, the light will likewise be transmitted so long as their axes are in the same direction; but if we fix E F and turn G H one quarter of a circle, as I K, the light will be stopped; if we turn it a second quarter, the light will be transmitted; and so on alternately, the light being transmitted when their axes are in the same direction, and stopped when at right angles to each other.

Fig. 13.



E F, G H, I K, plates of tourmaline.—The horizontal vibrations C D stopped by E F.—The perpendicular vibrations A B transmitted by E F and G H, but stopped by I K.

(49.) As in the former experiment, we can easily conceive that the particles A B vibrating in the direction of the axis of the crystal E F will be more likely to produce a continuation of the undulation than those of C D vibrating at right angles to the axis, and hence that A B will be transmitted and C D stopped.

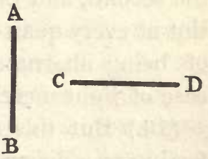
The tourmaline E F *polarizes* the light in the plane A B by stopping C D, which would otherwise form common light; and it is obvious that A B, after transmission through E F, would also be transmitted through G H, when its axis was in the same direction; but when G H is turned one quarter of a circle, as I K, its axis will be at right angles to A B, and will stop A B as E F had previously stopped C D. If we turn G H another quarter, A B will be again transmitted; and so on, the light polarized by E F being alternately stopped or transmitted by G H at every quarter of a revolution. A large portion of light is, however, lost, for one-half must be stopped to produce perfect polarization, besides what is lost by absorption, &c.

(50.) Light may also be polarized by transmission through other crystals possessed of the property of double refraction.

(51.) We have already shewn (35) that a ray of light transmitted through a doubly refracting medium suffers bifurcation, producing what are termed the ordinary and extraordinary rays. If these be examined, the rectangular planes of vibrations of the incident common-light will appear to have been separated in their passage through the crystal, the one plane forming the ordinary and the other the extraordinary ray; hence, both rays will be *polarized*, and in planes at right angles to one another.

A B, *Fig.* 14, represents the ordinary and C D the extraordinary rays, by which the two images are produced. If these be viewed through the tourmaline E F, *Fig.* 13, with its axis in the same direction as A B, the image produced by A B will be seen, and that formed by C D will be cut

Fig. 14.



A B the perpendicular, C D the horizontal vibrations, as separated by a doubly refracting crystal.

off. On turning E F 90 degrees, as I K, the image produced by A B will disappear, and that formed by C D will appear; and so the images will alternately appear and disappear at every quarter of a revolution of the tourmaline.

(52.) If, however, the tourmaline be turned only 45 degrees, two faint images will be observed; hence it has been assumed that polarized light is transmitted, when the plane of vibration does not vary more than 45 degrees from the axis of the tourmaline, or other polarizing plate, but is effectually stopped by a difference of 90 degrees.

(53.) In the preceding experiments we have seen that light polarized by one plate is alternately stopped and transmitted at every quarter of a revolution of a second polarizing plate; but if we interpose another doubly refracting crystal, a new and interesting series of phenomena will occur.

(54.) We have shewn that colors are produced by the interference of the ethereal waves (32); that a minute difference in the distances through which such waves are propagated is necessary to cause interference, otherwise they would always meet in the same state of vibration (33); and that a difference is occasioned by the bifurcation of a ray when transmitted through a doubly refracting medium, one part being always more refracted than the other, and hence pursuing a different course, and being of a different length (34).

(55.) If, then, we interpose between the tourmalines, or other polarizing plates, a doubly refracting medium, such as a plate of selenite, color will be produced by interference when the light polarized by the first plate is analyzed by the second, and the color will change to its complementary tint at every quarter of a revolution of the analyzer, instead of being alternately stopped and transmitted, as in the case of light merely polarized.

(56.) But this subject will be better understood by referring to a diagram exhibiting at one view the effects produced by the polarization, analyzation, and interference of light.

Fig. 15.

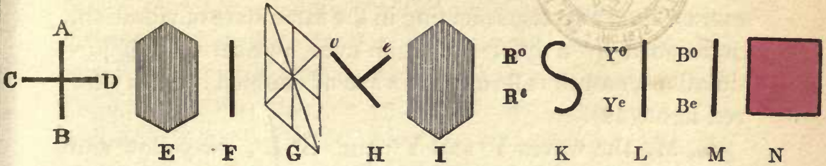


Fig. 16.

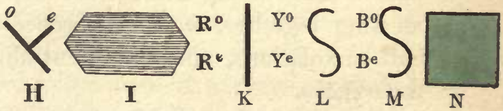


Fig. 15.—A B, C D, common light.—E, a plate of tourmaline termed the polarizer.—F, polarized light.—G, a plate of selenite.—H, dipolarized light.—I, a plate of tourmaline termed the analyzer.—K, coincidence of waves for red light.—L, interference of waves for yellow, and M of those for blue light.—N, the result—red light.

Fig. 16.—I, the analyzer turned round 90°.—K, interference of waves for red light.—L, coincidence of waves for yellow, and M of those for blue light.—N, the result—green light.

A B, C D, represent the rectangular vibrations by which a ray of common light is supposed to be propagated.

E, a plate of tourmaline, called in this situation the polarizer, and so turned that A B may vibrate in the plane of its crystallographical axis.

F, light polarized by E, by stopping the vibrations C D, and transmitting those of A B.

G, a piece of selenite of such a thickness as to produce red light, and its complementary color green.

H, the polarized light F bifurcated, or divided into ordinary and extraordinary rays, and thus said to be dipolarized by the double refractor G, and forming two planes of polarized light *o* and *e*, vibrating at right angles to each other (51).

I, a second plate of tourmaline, here called the analyzer, with its axis in the same direction as that of E, through which the several systems of waves of the ordinary and extraordinary rays H, not being inclined at a greater angle to the axis of the analyzer than that of 45 degrees, are transmitted (52) and brought together under conditions that may produce interferences (54).

K, the waves R^o and R^e for red light of the ordinary and extraordinary systems meeting in the same state of vibration, occasioned by a difference of an even number of half undulations, and thus forming a wave of doubled intensity for red light (32).

L, M, the waves Y^o and Y^e and B^o B^e, for yellow and blue of the ordinary and extraordinary systems respectively meeting together, with a difference of an odd number of half undulations, and thus neutralizing each other by interferences.

N, red light, the result of the coincidence of the waves for red light, and the neutralization by interferences of those for yellow and blue respectively (32).

H, *Fig.* 16, dipolarized light, as H, *Fig.* 15.

I, the analyzer turned one quarter of a circle, its axis being at right angles to that of I, *Fig.* 15.

K, the waves R^o R^e for red light of the ordinary and the extraordinary systems meeting together with a difference of an odd number of half undulations, and thus neutralizing each other by interference.

L, M, the waves Y^o Y^e and B^o B^e for yellow and blue of the two systems severally meeting together in the same state of vibration, occasioned by the difference of an even number of half undulations, and forming by their coincidences waves of doubled intensity for yellow and blue light.

N, green light, the result of the coincidences of the waves for yellow and blue light respectively, and the neutralization by interference of those for red (32).

(57.) By using a plate of selenite of uniform thickness, the color will be uniform, whereas a plate of different thicknesses will produce different colors following the same order as those of Newton's rings; red being produced by the thickest, violet by the thinnest, and intermediate colors by intermediate thicknesses of the plates of selenite.

(58.) Hence, also, if we examine under the microscope by polarized light any minute animal or vegetable tissues, possessing by means of their unequal densities or elasticities the properties of double refraction, there will be produced colors varying according to the otherwise unappreciable difference of density in the various parts of the tissues, which may thus be distinguished and traced out in a much more satisfactory manner than could be accomplished by common light. Should, however, the doubly refracting properties of the tissue be too feeble to produce a sufficient difference of color, the effect may be considerably increased by placing the object on a plate of selenite of uniform thickness; for which purpose a thickness of selenite producing a bright purple or light blue color will be found to afford the most agreeable contrast, and, as a single plate, to be the most generally useful*.

(59.) If we use a doubly refracting prism as an analyzer, and interpose a plate of selenite of uniform thickness, the complementary colors will be seen at the same time, and we are thus afforded a beautiful illustration of the decomposition and recomposition of white light. For this purpose a plate of selenite of that thickness which gives a *bright red* (and its complementary color green) should be selected, and laid on the stage of the microscope under a thin brass plate, having three circular perforations of different diameters, the smallest being so adjusted, both with respect to the power of the microscope and the separating properties of the double refractor, as that the two circles produced by double refraction shall just be distinctly separated: the second and larger perforation is to be made at such a distance from the first, and the third and largest at such a distance from the second, as to be successively brought into the field of view merely by the action of the lever or rack-work.

(60.) If the selenite be viewed through the smallest perforation without the doubly refracting prism, a disc of white light will be perceived. If the prism be now placed over the eye-piece of the microscope, the white light will be decomposed by interferences; a disc of red light will be seen on one side, and a disc composed of yellow and blue, forming by their combination green, or the complementary color to red, will be observed on the other: and that these colors are complementary, *or that the one is what the other wants to form white light,* may be proved by bringing the larger aperture into the field, when the diameters of the discs of red and green light will be so increased as to overlap, and form by their union white light, while the parts of each disc which do not combine will retain their respective colors. If the prism be turned round on its axis, the colors will change; but white light will always be seen where the complementary colors overlap and combine.

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* Mr. Darker has constructed a very convenient apparatus, consisting of three plates of selenite of different thicknesses, made to revolve in a frame, so as to produce, when required, different colors and their complementary tints.

(61.) If, instead of a plate of selenite, we interpose between the polarizer and the analyzer one of the crystals of calc. spar, quartz, topaz, nitre, arragonite, or the tourmaline, provided the plates be cut in certain directions, colored rings will be produced, which will change to their complementary colors at every quarter of a revolution of the analyzer. In some instances the rings will be intersected by a cross, which will be black when the axis of the analyzer is at right angles to that of the polarizer, and white when in the same direction; for in one case the light will be merely stopped, and in the other transmitted.

(62.) There is in every doubly refracting crystal at least one direction in which no double refraction takes place, for there must be one line where two opposing forces (34) meet, and neutralize each other: this line is called by some the *optic axis,* and by others, more intelligibly, the *axis of* [no] *double refraction.* If, then, there be any part of a crystal in which double refraction does not occur, the same effect will be produced, when the light transmitted through such part is analyzed, as though no doubly refracting crystal had been interposed, and the light will be merely stopped or transmitted by revolving the analyzer; but as double refraction takes place all around the axis, the systems of waves thus produced will interfere when analyzed, and occasion concentric colored rings. If a crystal possess but one axis of [no] double refraction, one system of colored rings, intersected by the effects of the light not doubly refracted, and, consequently, merely stopped or transmitted, will appear: if the crystal have two such axes, two systems will be produced, though in some instances they may be too widely separated to be observed at the same time.

(63.) My friend, Dr. Pereira, has beautifully exemplified this subject in his "LECTURES ON POLARIZED LIGHT;" and has shewn that such is the mutual relation existing between the forms and properties of crystals, that the form at once indicates whether or not a crystal possesses the property of double refraction, and, if a double refractor, whether it has one or two axes of [no] double refraction.

To this work I refer those who, having stepped over "the threshold," are inclined to study the higher branches of this interesting subject.

(64.) In the diagram, *Fig.* 15, one tourmaline is supposed to be used as a polarizer, and another as an analyzer; but the most generally useful polarizer for the achromatic microscope is a Nicols' prism; a doubly refracting crystal so prepared, that one of the images produced may be cut off or thrown out of the field. If a polarizer of large diameter should be required, a bundle consisting of from 16 to 18 plates of the thin glass used for covering microscopic objects, adjusted at the polarizing angle, may be substituted for the Nicols' prism. The most convenient analyzer is a thin plate of blue tourmaline; a Nicols' prism may, however, be used as an analyzer; but if placed over the eye-piece, the field of view is too much contracted; and if inserted in the body of the microscope, the prism can neither be conveniently turned nor readily removed.

(65.) A bundle composed of eight or ten plates of thin flat white window glass, the lowest plate being blackened to absorb the transmitted light, is the most convenient polarizer for the hydro-oxygen polariscope, because a field of view to any extent may be thereby obtained. Perfect polarization cannot, however, be produced by this means; for the light cannot fall upon and be reflected by all the surfaces at precisely the same angle. A single plate of blackened glass may be successfully substituted as a polarizer for the *table polariscope;* but the advantage of the complete polarization thus obtained is so much diminished by the decreased intensity of the light reflected, that the single plate can only be used with the *hydro-oxygen polariscope*, for the purpose of proving that the light polarized by the reflector is completely stopped by the analyzer at the alternate quarters of its revolution.

(66.) When, also, it is required to exemplify the above facts by the achromatic microscope, either a plate of tourmaline must be used as a polarizer, or a plate of blackened glass inclined at the polarizing angle* must be substituted for both the Nicols' prism and the ordinary reflector. For if light reflected by a metallic surface be transmitted through a Nicols' prism, it will be found that the emerging ray is not entirely polarized in one plane; and, therefore, a plate of tourmaline or other analyzer will not entirely cut off the light at every quarter of its revolution.

(67.) If animal structures or vegetable tissues are to be examined by polarized light, the blue tourmaline is the best analyzer; and in order to admit more light, and interfere less with the colors of the object, the plate may be ground very thin without injuring its analyzing properties for such purpose; but when the crystals of calc. spar, nitre, quartz, &c. are to be examined, the analyzing plate must not be ground so thin: for the more perfect the analyzer as well as the polarizer, the more beautifully will the various systems of colored rings be developed; and in this case also the blue tourmaline is the best analyzer; for although a light orange-colored tourmaline appears to afford the best definition, it interferes too much with the colors of the rings*. The quality of a tourmaline does not, however, depend merely on its color. Those are generally the best which stop the most light when their axes are placed at right angles, and yet admit the most when in the same plane; and certainly the less color, or the more it approaches to a neutral tint, the better.

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* This is readily effected by inclining the body of the microscope itself at the polarizing angle for glass, which is at once ascertained by holding at the side of the microscope a card cut to the proper angle, and comparing the angular position of each. If the blackened glass be then laid upon the ordinary reflector, previously placed in a horizontal position, and the lamp moved until the field be illuminated, the incident light must impinge upon the glass at the proper angle, the angle of reflection being equal to the angle of incidence. Messrs. Smith and Beck have recently adapted to the author's microscope a very simple indicator, which correctly points out the polarizing angle for glass, and supersedes the use of the card.

(68.) Thus we have endeavoured to explain and illustrate, in a familiar manner, some of the phenomena connected with the polarization of light, and have adopted the language of the undulatory theory, because it will enable the inquirer, at least, to comprehend what is meant by the terms used; but, as we have before observed, whether the theory be correct or not, the facts as illustrated by it remain the same. Newton called certain spaces fits of easy transmission and reflection; these are now generally supposed to indicate the length of half undulations. Future philosophers may call them by some other name; but, whatever theory is adopted, "these spaces," as it has been observed by Sir John Herschell, "have a real existence, being deduced by Newton from direct measurement, and involve nothing hypothetical but the names given to them."

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* The effects of these crystals may be exhibited with the achromatic microscope, by using the three-inch power racked down as near the Nicols' prism as the works will permit; and attaching the second eye-piece, taking off the cap or stop, and adapting to the eye-lens a small stage for holding the crystals and analyzer; but the field of view thus obtained is too limited for observing at the same time the widely separated systems of rings of arragonite. In order to examine to the best advantage the different crystals, an adjustment of the field of view is necessary. This is accomplished by constructing an eye-piece with the field-lens attached to a separate tube sliding within the one containing the eye-lens, and so arranged that the distance between the lenses may be increased from 1½ to 2¼ inches. Lenses of the same foci as those used in the second eye-piece, but of somewhat larger diameters, and fitted without a stop between them, answer the purpose very well. The field-lens is to be drawn out when calc. spar is examined, and moved back, as near to the eye-lens as the tubes will permit, when arragonite is viewed. An intermediate adjustment may be required for the inspection of other crystals, and is readily obtained by this means. A superior illumination of the field is effected by substituting for the three-inch power the lens usually employed as the side illuminator, bringing it by the action of the universal joint between the lower end of the microscope and the Nicols' prism. The illumination can then also be *adjusted*, and the light condensed upon any particular part, or diffused more generally over the field, by moving the lens nearer to, or farther from, the Nicols' prism. A plate of blackened glass placed at the polarizing angle, as before described, may be very advantageously substituted for the Nicols' prism, when a lamp is used for illuminating the field.

(69.) If, then, the undulatory theory can furnish the student with such a material vehicle as will convey the facts to his mind, and impress them on his memory, he may safely receive it until some better be propounded, when he can readily separate the facts from the terms, and adopt a more suitable nomenclature.

PART II.

DESCRIPTION OF, AND INSTRUCTIONS FOR USING, THE TABLE AND HYDRO-OXYGEN POLARISCOPE AND MICROSCOPE.

(70.) This instrument is so arranged that it may be illuminated by a candle or argand lamp placed on the table, as in the case of an ordinary microscope; or, with the addition of suitable condensers, it may be attached to the lantern of the hydro-oxygen apparatus, and used either as a gas polariscope or microscope for illustrations in the lecture room.

Fig. 18.

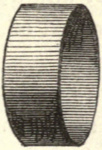

Fig. 17.

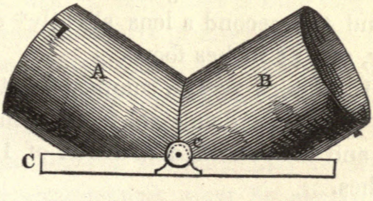

Fig. 17.—The polariscope.
Fig. 18.—A cap with a ground glass shade.
On a scale of one quarter to an inch.

(71.) A B, *Fig.* 17, represents the body of the polariscope formed of two tubes three inches diameter, each inclined at the polarizing angle for glass, viz. 56° 45′.

C, the polarizing plates, consisting of eight pieces of thin white window glass, the lowest being blackened to absorb the transmitted light. These are attached to the polariscope by screws, *c*, and removable at pleasure.

Fig. 18, a cap fitting on at A, formed by a ring enclosing a piece of ground glass to disperse the light of the candle or lamp used as an illuminator.

Fig. 19.

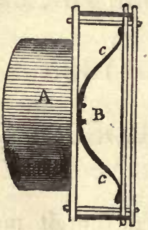

Fig. 19.—The stage.

Fig. 20.

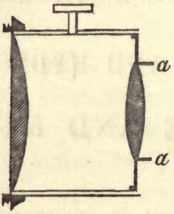

Fig. 20.—The power.

Fig. 21.

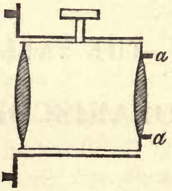

Fig. 21.—A higher power.

On a scale of one quarter to an inch.

Fig. 19, A, a tube fitting on at B, *Fig.* 17, and fixed by a bayonet catch. B, the stage attached to and revolving around the tube A, the objects being kept in position by the springs *c c*.

Fig. 20, the lowest power to be screwed into the stage B, *Fig.* 19. It is composed of two lenses, the first being a plano convex lens of 2⅞ inches diameter, and 3½ inches focus, and the second a lens slightly* crossed of 1¾ inch diameter, and 2½ inches focus.

Fig. 21, a higher power, composed of two crossed lenses, the first having a diameter of 1¾ inch, and focus of 2½ inches; and the second a diameter of 1½ inch, and focus of 2 inches.

(72.) The tourmaline, or other analyzing plate, turns freely in a short tube, *a a*, projecting from the eye-lens of the power, and the focus is adjusted by a rack and pinion.

(73.) A box 9 inches high and about 11 inches long, by

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[*] By a crossed lens is understood a double convex lens, the two sides of which are segments of circles of different diameters.

7 wide, will contain the whole, and may be conveniently fitted as a stage to raise the polariscope to a convenient height for illuminating and viewing objects on the table. A sketch of the apparatus arranged for use has been taken by my friend, Mr. Legg, by means of the camera lucida attached to a microscope fitted with "Smith and Beck's erecting piece," and is represented in *Fig.* 22.

Fig. 22.

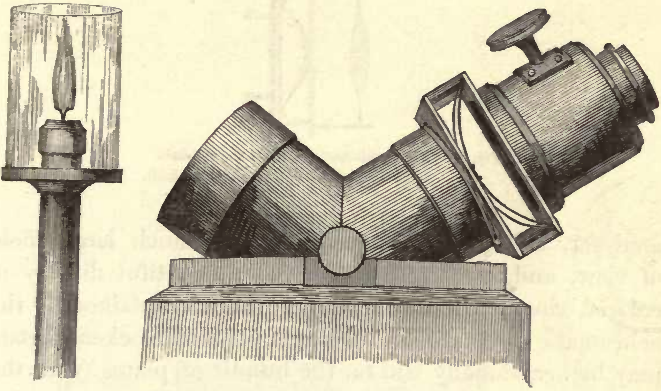

Fig. 22.—The table polariscope arranged for use.

(74.) The instrument arranged with the lowest power affords an extensive field of view, and is thus well adapted for exhibiting the various effects produced by the different forms and thicknesses of selenite and unannealed glass, and for illustrating the interesting phenomena of polarized light generally. It is also calculated for viewing such crystals of salts as have been allowed spontaneously to crystallize on glass; but the arrangement must be altered for observing the phenomena connected with the crystals of calc. spar, nitre, quartz, &c. In the one case, the lens or power is used to bring the image of the object to a focus; in the other, it is merely required to cause a great divergence of the rays passing through the crystals; hence, the slide containing them must either be placed immediately between the eye-piece and analyzer by means of a small stage attached to the tube *a a* of the power, or the stage and power must be removed, and there must be inserted instead a double convex lens of two inches focus, with a stage and analyzer so arranged that the crystals may be placed just within the focus of the lens, and immediately under the analyser, as *Fig.* 23. In either case, a much larger field of view, and, consequently, a more beautiful display of colored rings, will be developed than is obtained by the achromatic microscope. A single plate of blackened glass may be occasionally laid on the bundle of plates (with the intervention of a piece of chamois leather, to prevent injury), and substituted with advantage as a polarizer in cases where perfect polarization is more important than intensity of light (65).

Fig. 23.

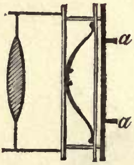

Fig. 23.—The condenser and stage for crystals. On a scale of one quarter to an inch.

(75.) By removing the analyzer and the polarizing plates, and substituting for the former a cap or stop with an aperture of $\frac{7}{8}$ inch diameter, and for the latter a silvered reflector, or, in other words, a looking-glass, the polariscope is immediately converted into a microscope of low power, which will include within its field all the parts of a large object, such as a butterfly with its wings extended, the breathing apparatus of a dytiscus, a fern branch, dissected leaf, &c.; and thus exhibit at one view their relative proportions and connections.

(76.) The polariscope may also be attached to the hydro-oxygen lantern, and adapted for illustrations before a large audience. An apparatus described below, fitted up for this purpose at a comparatively small expense, has been long used by the author, who considers it to possess great power, and to be more convenient for private investigation than any other, while it is equally well adapted for illustrations in the lecture-room. The arrangement of the condensers and powers is the result of very many experiments continued through several years, and, hence, a particular description of them is given (*Figs.* 20, 21, 23, 25, 26, 27).

Fig. 24.

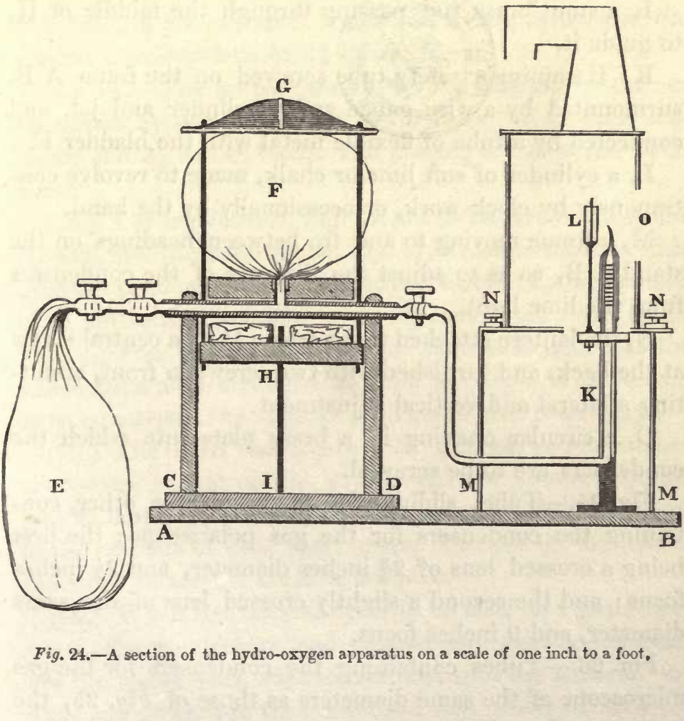

Fig. 24.—A section of the hydro-oxygen apparatus on a scale of one inch to a foot.

(77.) A B, *Fig.* 24, represents a stand or frame upon which are placed a Gurney's blow-pipe, and the lantern.

C, D, two of the upright pillars fixed into a stout stand,

and supporting a corresponding piece of wood, to which are attached the tubes leading from the reservoir E to the bladder F*, and from thence to the safety tubes, K.

G, a very light circular board strengthened by thin pieces of wood placed vertically at right angles to each other, and fastened with packthread to rings inserted through the four wires connected with the pressure board H, upon which are placed flat leaden weights. The pressure is temporarily removed for the purpose of filling the bladder F from the reservoir E, by raising the pressure board H, and suspending it by two rings turned over corresponding hooks in the upper part of the frame.

I, a stout brass rod passing through the middle of H, to guide it.

K, Hemming's safety tube screwed on the frame A B, surmounted by a wire gauze safety cylinder and jet, and connected by a tube of flexible metal with the bladder F.

L, a cylinder of soft lime or chalk, made to revolve continuously by clock-work, or occasionally by the hand.

M, a frame moving to and fro between beadings on the stand A B, so as to adjust the distance of the condensers from the lime light.

N, the lantern attached to the frame M by a central screw at the back, and furnished with two screws in front, admitting a lateral and vertical adjustment.

O, a circular opening in a brass plate into which the condensers are to be screwed.

Fig. 25.—Tubes sliding the one within the other, containing the condensers for the gas polariscope; the first being a crossed lens of 2¾ inches diameter, and 2½ inches focus; and the second a slightly crossed lens of the same diameter, and 9 inches focus.

Fig. 26.—Tubes containing the condensers for the gas microscope of the same diameters as those of *Fig.* 25, the

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* Light indian rubber bags of suitable forms may be substituted for the bladders E and F.

Fig. 25.

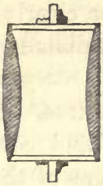

Fig. 26.

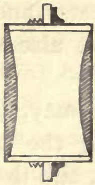

Fig. 27.

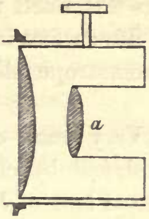

Fig. 25.—Condensers for the gas polariscope.
Fig. 26.—Condensers for the gas microscope.
Fig. 27.—The lowest power adapted for the gas polariscope or microscope.
On a scale of one quarter to an inch.

first being a plano-convex lens of 3½ inches focus, and the second a crossed lens of 4½ inches focus.

Fig. 27.—The lowest power, *Fig.* 20, adapted for the gas apparatus by substituting an eye lens (*a*) of 1½ inch diameter and 2⅜ inches focus, and placing it nearer the field-lens.

(78.) The condensers, *Fig.* 25, are to be screwed into the lantern, and the polariscope, *Fig.* 17, which is made to slide over the condensers, must be turned sideways, and fastened in a horizontal position by a bayonet catch: the stage, *Fig.* 19, and power, *Fig.* 21, are then attached, and the whole apparatus arranged at such an angle to the screen as to counteract the angular position of the polariscope.

(79.) The most useful power for the gas polariscope or microscope is that of *Fig.* 21, though the power, *Fig.* 27, may be employed for very large objects; but with reference to the crystals of calc. spar, nitre, &c. one of the modes described in sec. 74 must be adopted.

(80.) When the instrument is to be used as a gas microscope, the condensers and polariscope must be removed, and the condensers, *Fig.* 26, screwed into the lantern; the stage and power are then attached and fastened with the bayonet catch as before described.

(81.) If the power, *Fig.* 27, be substituted for that of *Fig.* 21, and the microscope be placed at a distance of six or seven feet from the screen, the image of a butterfly with its wings extended may be so magnified as to occupy a space of fifteen feet in diameter, and yet be clearly defined. The chromatrope slides are also well exhibited with this power.

(82.) Very small objects may, nevertheless, be beautifully displayed by changing the powers and condensers. The crossed lens of *Fig.* 25, and the eye-lens of the power, *Fig.* 20, which is never used as such with the gas apparatus, appear to form the best condensers for the high powers; these need not, however, be separately fitted up, as there is no difficulty in changing the relative situations of any of the lenses used as condensers; but in all cases they must be especially arranged with their most convex surfaces towards each other, and these may be immediately distinguished by observing the difference between the images of the flame of a lamp, or other object, as reflected by the respective surfaces, for the more convex the lens the smaller will be the reflected image. The bars of a window frame will be reflected in parallel lines by the plain side of a lens, but will appear to converge in proportion to the convexity of the reflecting surface, and thus a slight difference of convexity may be readily detected. It is also important that the condensers should be allowed a sufficient space for expansion in their cells; if they be burnished in, or screwed up too tightly, they will most probably be cracked by the heat of the flame and incandescent lime.

(83.) Condensers of greater diameters than three inches may be used; but numerous experiments have tended to prove that no adequate advantage is thereby obtained, unless the apparatus be supplied with the separate gases under very great pressure; and, except under the same circumstances, cylinders of soft lime or chalk are preferable to those of hard lime, as the latter require to be submitted to the action of the gases under much greater pressure than the former, in order to produce an equally intense degree of light.

The advantages of the above arrangement are—

(84.) That the apparatus occupies a small space, is readily prepared for use, and can be managed without the fatigue and inconvenience of filling large bags with gas, and of procuring and lifting heavy weights.

(85.) That one quart of oxygen* and two of hydrogen will be amply sufficient to enable the inquirer at any time to submit his suggestions to the test of experiment.

(86.) That the proper relative proportions of the gases are definitely fixed in the first instance.

(87.) That a waste of gas is prevented by the facility with which it can be turned off and re-lighted.

(88.) That an increased degree of light for producing any particular effect may be immediately obtained by the action of the hand on the pressure board.

(89.) That Mr. Gurney's apparatus may be detached, and, if furnished with his water safety chamber and jet, may be used for illustrations in the lecture-room, as the safest and most powerful hydro-oxygen blowpipe known.

(90.) Lastly, that the whole may be conveniently removed, as required for the purposes of the lecturer.

The supposed disadvantages are—

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* In consequence of the greatly reduced price of chlorate of potass, oxygen gas is now procured with as much facility as hydrogen. The best mode of obtaining it is to mix one portion of the black oxide of manganese with twice its weight of chlorate of potass, both previously reduced to a fine powder, which may be kept in a bottle for use as required. If a four-ounce glass retort be about half filled with this mixture, and the heat of a spirit lamp be applied, a large quantity of pure oxygen will be liberated in a few minutes. The operation does not succeed so well with a larger retort; but if four of these small retorts be used successively, as much oxygen will be obtained in half an hour as will displace six or seven pails of water. The residuum forms into a solid mass, but, being readily soluble in water, it may then be emptied into a vessel, and allowed to settle, when the water may be poured off, and the manganese, which only acts mechanically, may be dried, and again repeatedly used.

The most convenient method of receiving the gases, is to fix, within two inches of the bottom of a small trough or tub, a zinc receiver, furnished with two stop cocks at the top, to which bladders may be attached, and alternately changed, as one or the other becomes filled with gas.

(91.) First, that it is dangerous to use the gases previously mixed.

(92.) A series of experiments continued during many years has, however, proved that, while the bladder containing the mixed gases is *under pressure*, the flame cannot *be made* to pass the safety chambers, and, consequently, an explosion cannot take place; and even if through extreme carelessness or design, as by the removal of pressure, or the contact of a spark with the bladder, it should occur, it can produce no other than the momentary effect of the alarm occasioned by the report; whereas, when the gases are used in separate bags under a pressure of two or three half hundred weights, if the pressure on one of the bags be accidentally removed or suspended, the gas from the other will be forced into it, and, if not discovered in time, will occasion an explosion of a very dangerous character; or if, through carelessness, one of the partially emptied bags should be filled up with the wrong gas, effects of an equally perilous nature would ensue.

(93.) And, secondly, that as the bladder F must be frequently re-filled, the light cannot be continuous.

(94.) This is true, and forms some objection to the plan, where an apparatus is to be permanently fixed for public exhibition, though it might be obviated by adapting a second bladder to the safety tubes; but the objection does not apply in the case of the lecturer, whose assistant will have many opportunities of keeping up the supply of gas, while the lecturer himself explains his subject, or changes either the object or the power.

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